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Article

Assessment of the agro-industrial sugar yield of sugar mills in Mexico

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Abstract

In Mexico, sugarcane is important to guarantee the food sufficiency of standard sugar. This work aimed to evaluate the technical inefficiency of the agro-industrial sugar yield of the sugar mills in Mexico for the 2022-2023 harvest in order to identify the most inefficient sugarcane production units. The model used was the stochastic frontier analysis approach. The results showed that, of the 39 mills analyzed, a group of six mills showed the lowest performance in their agro-industrial yield of standard sugar indicator in the study harvest. These sugar mills and their respective efficiency were Puga (89.3%), Alianza Popular (88.9%), Plan de San Luis (88.5%), Plan de Ayala (88.3%), Progreso (85.6%), and El Mante (84.9%). The technical inefficiency of these six production units is greater than 10% and is due to inadequate management and poor production practices and not to random variables such as the climate. The main conclusion of the research is that 88.3% of the relative technical inefficiency in the agro-industrial yield of sugar per unit area is attributable to causes of the internal environment of such companies and only 11.7% to random factors outside the sugar mills.

Keywords:

composed error, sucrose in sugarcane, sugar per hectare, technical inefficiency.

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Introduction

According to INEGI (2021), the North American Industrial Classification System (NAICS) stipulates that the sugar industry is made up of cane sugar processing activities and the processing of other sugars. The production of cane sugar is thus composed of two main links.

The first is the one that goes from field activities to the placement of raw materials for the production of standard sugar on the patio of the sugar mill. The second link is made up of the cane milling activities until the sweetener itself is obtained, which is standard sugar (AMS, 2024). The sugarcane agribusiness is present in 22 states and is of great importance due to several economic precepts (CONADESUCA, 2023).

In the country, the importance of the sugar industry is relevant in terms of direct and indirect employment. The CNIAA cited by SE (2014) indicates that, in the sugar industry, the direct jobs generated in 56 mills that operated in the 2008-2009 harvest were 448 894.

According to SIAP (2024), in 2023, sugarcane participated with 5.8% ($52.90 million) of the value of agricultural production, only below grain corn, which ranked first with 19% ($172.40 billion), and avocado, which stood at $60.10 billion (6.6%) (SIAP, 2024). On the other hand, in Mexico, since the federal administration of 1988-1994, there has been a process of consolidation of the sugarcane agribusiness that has been reflected in the closure of physical plants and their concentration in 11 groups (CNIAA, 2024).

In 1988, 65 mills operated, whereas in the 2023-2024 harvest, only 49 mills did so. Thus, in 36 years, 16 sugar mills have closed; that is, 25.6% of the productive plant (Haley, 2000; CNIAA, 2024).

Financial problems, foreign competition, changes in government policies, labor conflicts, adverse climatic conditions, and lack of investment in technology and modernization have been the main causes that have led to the closure of these mills (CEFP, 2001; Campos and Oviedo, 2013; INEGI, 2021).

The closure of sugar mill operation is a process in which they begin to be affected by specific causes that ultimately lead them to the decline in their productivity and efficiencies, which ultimately lead them to be unviable both technically and economically and to leave the sugarcane agribusiness (Haley, 2000; SE, 2012).

The literature review did not yield research in Mexico that analyzes the closure of sugar mills due to their technical, cost, or allocative inefficiency using the parametric approach of the stochastic frontier. However, there are some studies that have determined technical efficiency, technological change and economies of scale of sugar mills. Santiago *et al*. (2021) determined the technical efficiency and technological change at the sugar mill level using the Malmquist index, and their results showed that, in the 2006-2007 and 2015-2016 harvest periods, the inefficiency of San Miguel del Naranjo sugar mill increased by 10.2%.

Technical efficiency has been analyzed in different parts of the world, including Africa (Onour, 2017), India and Brazil. Within this framework, this research aimed to evaluate the technical inefficiency of the agro-industrial sugar yield of the sugar mills of the sugarcane agribusiness in Mexico for the 2022-2023 harvest in order to identify the most inefficient sugarcane production units. It is hypothesized that the inefficiency of the sugarcane agribusiness will be largely explained by causes that are under the control of the management of the respective mill.

Materials and methods

To conduct the work, information from secondary sources and administrative records was used. The main source of statistical information for the study period was the statistical report on sugarcane agribusiness of the National Union of Sugarcane Growers (UNC-CNPR 2023). The variables used for the estimation of the empirical model are those defined in Table 1.

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Table 1 .Variables used in the empirical model of the technical inefficiency of the agro-industrial yield of sugar mills in Mexico.

Variable	Description	Units
agyisu	Agro-industrial yield of sugar produced per unit area	(t ha^{-1})
indar	Industrialized sugarcane area	(ha)
sucan	Sucrose content in sugarcane	(t ha^{-1})
wcto	Weighted cost of production of sugarcane	($ ha^{-1})

Regarding the variables, it is necessary to mention that the agro-industrial yield of standard base sugar per hectare is a concept defined in CONADESUCA (2023) as the tonnes of total sugar among the hectares of industrialized area, which are the hectares of industrialized sugarcane area of the respective mill.

The weighted cost of sugarcane production for the 2022-2023 harvest was estimated as an average of the cost of producing one hectare of sugarcane in the plant crop, first ratoon crop, and second ratoon crop stages, where the cost of each phase was weighted by the respective area, whether irrigated or rainfed. The information to estimate this cost can be found on the microsite called Si-costs of CONADESUCA (2024).

The method used to estimate the technical efficiency of sugar mills is the stochastic frontier model developed independently by Meeusen and Van den Broeck (1977) and Aigner *et al*. (1977). In econometrics, the stochastic frontier production function is used to estimate the inefficiency of production units using concepts from the theory of production economics and stochastic processes to separate random shocks from inefficiency in the production process (Kumbhakar and Wang, 2015).

According to Kumbhakar and Wang (2015), the general mathematical expression of the stochastic frontier production function for cross-section data has the following form:

$$Y_i= f(X_i; \beta) \exp(\nu_i-u_i)$$

1). Or in its logarithmic form:

$$\ln Y_i= \ln f(X_i; \beta)+(\nu_i-u_i)$$

2). Where: Y_i= output of the i-th production unit; X_i= vector of inputs for the i-th production unit; β= vector of parameters to be estimated; ($_i$= random error term that captures statistical noise; u_i= non-negative random variable that represents technical inefficiency; ln= natural logarithm; exp()= exponential function.

As can be seen, in the above expressions the term (($_i$-u_i) is a composed error. Where: ($_i$= random error term that explains random shocks, measurement errors and some other statistical noise, and it is common to assume that the statistical error is distributed with zero mean and constant variance.

$$(\nu_i \sim N(0, \sigma_\nu^2))$$

Regarding u_i this error term captures the inefficiency of the production unit and is not negative (u_i ≥ 0) and it is common to assume that it follows a half-normal distribution, an exponential distribution, or a truncated normal distribution, among others (Meeusen and Van den Broeck, 1977; Aigner *et al*., 1977).

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The parameters of the stochastic frontier production function; ie. β and σ_v^2 they are parameters that govern the distribution of u_i in practice estimated using maximum likelihood, which implies maximizing the likelihood function based on the joint distribution of the composed error term (($_i$-u_i) (Greene, 2008). Once the parameter vector β has been estimated, the technical efficiency of the (i-th) production unit (TE_i) is estimated from the following expression:

$$TE_i=E\left[\exp(u_i) \mid \nu_i\right]=\exp\left(-\mu_{*_i}+\frac{1}{2}\sigma_*^2\right)\frac{\Phi\left(\frac{\mu_{*_i}}{\sigma_*}-\sigma_*\right)}{\Phi\left(\frac{\mu_{*_i}}{\sigma_*}\right)}$$

3). Where: Φ()= is the cumulative distribution function of the standard normal distribution (Jondrow *et al*., 1982); TE_i= varies within the range; where a value equal to one indicates complete efficiency (no inefficiency) and a value less than one indicates the presence of inefficiency.

An advantage of stochastic frontier analysis is that it helps to separate technical inefficiency due to causes arising from the management of the company or production unit and the inefficiency associated with purely random shocks. The causes of non-stochastic technical inefficiency in companies or economic sectors can be due to several causes. Internal causes of technical inefficiency can be poor management of production units due to lack of managerial skills or incorrect decisions, inadequate training of personnel, outdated technology, failures in the maintenance of physical equipment and infrastructure, poor work organization, and lack of coordination between different units or departments.

The external causes that generate technical inefficiency are market conditions, government regulations and policies, limited access to financing, adverse climatic conditions, and poor infrastructure (transportation and communications). In the case of stochastic factors that cause technical inefficiency in production units, unpredictable events, such as natural disasters, unforeseen mechanical failures, or sudden changes in the economic environment, can cause inefficiency.

A major source of technical inefficiency has to do with the organizational culture of the production units. For example, organizations may be reluctant to change their methods of operation or adopt new technologies, so they may lag behind in terms of staff efficiency and motivation (low morale or lack of adequate incentives for workers in a unit can reduce their productivity and efficiency) (Aguilar *et al*., 2011).

The empirical model that was used to estimate the inefficiency of the agro-industrial yield of the production units of the Mexican sugarcane agro-industry is a stochastic frontier production function whose functional form is of the Cobb-Douglas type, which, when logarithms are applied to its left and right sides, takes the form of a logarithmic-linear model; that is, a form where the parameters to be estimated are linear. Following the convention that lowercase variables denote the logarithm of that variable, the mathematical expression of the empirical model has the following linear form:

$$agyisu=\beta_o+\beta_1 indar+\beta_2 sucan+\beta_3 wcto+(\nu_i-u_i)$$

4). Where: agyisu, indar, sucan and wcto are the variables defined in Table 1 and (($_i$-u_i) is the composed error term in which ($_i$ is the statistical error with the properties already mentioned in the preceding paragraphs, whereas u_i is the error that has a half-normal distribution and reflects the inefficiencies present in the production units with respect to the agro-industrial yield of standard sugar.

Both errors are independent of each other. Regarding the expected signs, an inverse relationship is expected between agro-industrial yield and the variables of industrialized sugarcane area and the weighted cost of production. Additionally, a direct relationship between agro-industrial yield and sucrose content in sugarcane is to be expected.

On the other hand, before proceeding to the analysis of the results, it is necessary to make clarifications regarding the definition of the variables used in the research. The concept of agro-

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industrial sugar yield is defined in CONADESUCA (2023) as the total sugar produced per unit of production among the industrialized sugarcane area.

In consultations with specialists on which variable could satisfactorily explain the agro-industrial yield of sugar, it would be expected to be the 'parameter' called 'kilograms of standard base recoverable sugar' or ksbrs ; however, in many runs of the empirical model, this variable turned out to be in all cases statistically non-significant and with the opposite sign to that expected, that is, instead of a direct relationship of ksbrs with the agro-industrial yield of sugar, an inverse relationship was obtained.

In the case of the variable of sucrose content in sugarcane, it was statistically significant and with a direct relationship with agro-industrial yield. The estimation of the empirical model was carried out with the R-frontier 4.1 package (Coelli and Henningsen, 2020). The frontier package is the R-language programming of Coelli's (1996) software.

Results and discussion

Once the variables that best fit the empirical model and whose individual parameters were statistically significant as explanatory variables were identified, the estimation of this model was carried out. The estimated econometric results, by maximum likelihood of the stochastic frontier production function of the agro-industrial sugar yield of the sugar mills of Mexico, are shown in Table 2.

Table 2. Estimated parameters of the stochastic frontier production function of agro-industrial sugar yield.

Parameter	Estimated value	Standard error	z-value	Pr > I z I
Intercept	2.5958232	0.3853959	6.7355	0
indar	-0.8222068	0.0305038	-26.9542	0
sucan	0.7895521	0.0300981	26.2326	0
wcto	-0.0330033	0.0651852	-0.5063	0.612545
σ_v^2	0.0073742	0.0040585	1.8169	0.069226
σ_u^2	0.8321788	0.2952273	2.8188	0.004821

In the output of 'R frontier 4.1', σ_u^2 is referred to as 'gamma'.

As observed in Table 2, the expected signs are the correct ones. The t statistic shows that the industrialized area (indar) and sucrose in sugarcane (sucan) are highly significant, with a value of -26.9542 and 26.2326, respectively. However, the value of t associated with the weighted cost of production (wcto) is not statistically significant at any of the usual confidence levels, but it is retained because it has the correct sign.

In this way, an inverse relationship between the agro-industrial yield of sugar per hectare with the industrialized area and the weighted cost of production of sugarcane was analyzed. Similarly, there is a direct relationship between agro-industrial yield and sucrose content in sugarcane. Additionally, as can be seen in the last row of the table, the estimated value of σ_u^2 (gamma) is 0.8829, which implies that 88.3% of the variance is explained by technical inefficiency and the rest (11.7%) of the variance is explained by random factors.

According to Schmidt and Campión (2006), when σ_u^2 (gamma) is zero, the efficient frontier estimated by maximum likelihood coincides with the frontier estimated by ordinary least squares and the error term is totally stochastic. On the other hand, to test the null hypothesis that all parameters are not significantly different from zero, the statistical test of generalized likelihood ratio (LR) is used, which follows an asymptotically distributed χ^2 distribution.

In the context of the stochastic frontier model, this implies comparing the model without technical inefficiency, that is the one estimated by ordinary least squares, against the so-called error component frontier(ECF) model (Coelli, 1995), which is estimated by maximum likelihood (Coelli

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and Battese 1995). The R-frontier 4.1 package directly provides the generalized likelihood ratio and the contrast test was performed as shown in Table 3.

Table 3. Hypothesis testing of the stochastic frontier inefficiency model

Hypothesis	Model	Generalized likelihood ratio	Degrees of freedom	χ^2	Pr (>χ^2)
H_0	Non-inefficiency (OLS)	72.6			
H_a	Error component frontier (inefficiency)	75.258	1	5.3162	0.01056*

* = significant at 99%; OLS= ordinary least squares.

As perceived, the absolute value of the generalized likelihood ratio is 75.258, which indicates that, with the 99% confidence level, the null hypothesis that there was no presence of inefficiency in the production of standard sugar per unit area of Mexico's sugar mills in the 2022-2023 harvest is rejected.

On the other hand, Table 4 shows the estimated technical efficiency of the agro-industrial sugar yield for the 39 sugar mills for which complete statistical cost information was available for the 2022-2023 harvest.

Table 4. Technical efficiency of Mexico's sugar mills in the 2022-2023 harvest.

	Sugar mill	Technical efficiency (%)		Sugar mill	Technical efficiency (%)
1	Huixtla	98.6	21	La Providencia	94.8
2	El Modelo	98.3	22	Tres Valles	94.6
3	San Pedro	97.7	23	Casasano	94.3
4	Eldorado	97.6	24	Bellavista	93.4
5	Tala	97.3	25	Constancia	93.1
6	La Gloria	97.3	26	Santa Clara	92.8
7	Benito Juárez	97.3	27	El Potrero	92.1
8	El Carmen	97.1	28	Quesería	92
9	Atencingo	97	29	Emiliano Zapata	92
10	El Higo	97	30	Lázaro Cárdenas	92
11	Melchor Ocampo	96.9	31	Pedernales	92
12	San Nicólas	96.7	32	Cuatotolapan	91.3
13	Pujiltic	96.5	33	La Margarita	90.3
14	Mahuixtlán	96.5	34	Puga	89.3
15	San Cristóbal	96.2	35	Alianza Popular	88.9
16	Tamazula	95.8	36	Plan de San Luis	88.5
17	José María Morelos	95.8	37	Plan de Ayala	88.3
18	Zapoapita	95.5	38	Progreso	85.6
19	Santa Rosalía	95.4	39	El Mante	84.9
20	San Rafael	95.3	40	Agroindustria cañera	94

Source: based on the R-frontier 4.1 output.

In this way, it has been found that the average technical efficiency of the agro-industrial sugar yield of the sugarcane agribusiness in Mexico was 94%, so there is an inefficiency of 6% in it. Thus, of 39 sugar mills evaluated with the stochastic frontier approach, two of them have the highest technical efficiency, which are Huixtla and El Modelo with a technical efficiency of 98.6% and 98.3%, respectively, so it can be considered that their technical inefficiency is not relevant in their agro-industrial yield of standard sugar.

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A second group with a technical efficiency greater than 95% and less than 98% comprises 18 mills. A third group with an efficiency between 90% and 95% comprises 13 mills, which therefore present some inefficiency in their agro-industrial yield indicator. A fourth group is one whose efficiency is less than 90% and includes six mills, which are the Puga (89.3%), Alianza Popular (88.9%), Plan de San Luis (88.5%), Plan de Ayala (88.3%), El Progreso (85.6%) and El Mante (84.9%) mills.

It can be argued that the high technical inefficiency of the indicator of standard sugar per unit area (ie. agro-industrial sugar yield) may compromise the viability of such production units. For instance, in the case of the El Mante sugar mill, its efficiency is less than 90%, so its situation can be considered critical because its technical inefficiency is greater than 10%. As can be seen, these two mills are El Mante, with an inefficiency of 11.4% and El Carmen, with a technical inefficiency of 15.1%.

It is important to mention that, in recent years, both the El Mante and El Carmen sugar mills have had management and liquidity problems. El Mante has been in trouble for more than 30 years because, for its privatization in 1988, it declared bankruptcy irregularly, so since then, there has been a movement of former cooperative members that demands the annulment of the aforementioned bankruptcy. The problems of El Mante increased from the 2012-2013 harvest, when there was a drop in the price of sugar that affected the price paid for the raw material, which is sugar cane.

El Mante began a new administration in 2020 under the direction of the Pantaleón Group, originally from Guatemala. In previous years, the management of this mill was exercised by the Sáenz Group, which is accused of having mismanaged said production unit (Expreso.press, 2015). In the case of El Carmen, there have been financial and liquidity problems for several years, both for its modernization and to meet the labor demands of its workers and its suppliers.

In this way, it is possible that the technical inefficiency of both mills may have its origins in this and some other kind of problem; for example, organizational problems. The stochastic frontier approach to evaluate the performance of productive units through their relative technical efficiency has been applied to a wide variety of economic sectors. In the case of agriculture, particularly in the sugarcane agribusiness, the stochastic frontier model, as far as is known, has not been applied in Mexico.

A problem with the reviewed studies from other countries is that the estimate of inefficiency in most cases refers to family production units or small and medium-sized sugarcane producers, but not to the sugar mills because the information on them is not recorded as in the case of Mexico at the sugar mill level, and the same happens for the large number of variables that are included, for example, in UNC-CNPR (2023).

This problem occurs; for example, in Murali and Puthira (2016), which is a research carried out for India. This country is the world's second largest producer of sugarcane. The research used a random sample of 198 production units in Tamil Nadul and econometrically estimated an average technical efficiency of 82% using the stochastic frontier.

This average efficiency is for the sugarcane production units at the producer level, but not for the agribusiness made up of all its sugar mills in that country. In this way, the results of this study are at the level of sugar mill, so the results of other studies are, in any case, comparable as they are results for small and medium-sized producers.

Conclusions

The evaluation of the agro-industrial yield of standard sugar of the sugar mills with the stochastic frontier production function model made it possible to determine that, among these production units, 88.3% of the relative technical inefficiency in the agro-industrial yield of sugar per unit area is attributable to causes of the internal environment of such companies and only 11.7% to random factors outside the sugar mills.

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The average technical inefficiency of the sugarcane agribusiness was 3.9%. The analysis found that the El Higo and Huixtla mills are, in relative terms, the most efficient in terms of agro-industrial sugar yield since their efficiency was 99.3%, which indicates that, in practice, both mills do not face any type of inefficiency attributable to the management of both production units.

Nonetheless, two mills whose technical inefficiency of agro-industrial sugar yield is high were identified. These were El Mante and El Carmen, with a technical efficiency of 88.6% and 84.9%, respectively. The high technical inefficiency of these two mills, at least in their agro-industrial yield of standard sugar, increases the risk that may compromise their viability to continue operating.

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